PERIODIC PROGRESS REPORT NO. 4

FOR

STUDY OF COMMUNICATIONS SYTEMS, AND
DETECTION AND TRACKING SYSTEMS.

DESIGN AND FABRICATION OF DYNAMIC CROSSED-FIELD
ELECTRON MULTIPLYING LIGHT DEMODULATOR.

20 DECEMBER 1964 TO 20 MARCH 1965

Contract No.: NAS5-3777

Prepared by

The Hallicrafters Co.
5th and Kostner Avenues
Chicago, Illinois 60624

for

Goddard Space Flight Center
Greenbelt, Maryland

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Prepared by:

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ABSTRACT

This fourth quarterly report presents results of an optical communications and tracking systems program divided into three specific Tasks as follows:

Task I: Analyze laser communications, detection, and tracking systems

Task II: Disseminate the results of Task I through a lecture series and through development of a manual collating materials of Task I and the lecture series, and

Task III: Development, improvement and delivery of microwave bandwidth dynamic crossed-field electron multiplier demodulators with various characteristics.

These Tasks reflect additional work to be performed under Modification No. 1 to the subject contract.

Theoretical work under Task I was completed in the third quarter. Work in the fourth quarter is reported for Tasks II and III.

Work on Task II for the fourth quarter consisted of developing the first half of a manual covering radiation laws and statistics, noise and fluctuations, detection statistics and information theory aspects. Work on this portion of the manual will be essentially completed in the next period and effort will be directed to the second part of the manual.

Work on Task III consisted of reduction of the drive power requirement to 1.75 watts, evaluation of mesh pedestals, fabrication of new detectors, and initiation of a photo-surface and a permanent magnet investigation. A detector with reduced power input requirements was fabricated and delivered, complete with holder/electromagnet assembly and detailed operating instructions.

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1. TASK II EFFORT

1.1 Introduction

Task II, as modified, consists of a series of ten lectures, each four hours in duration to be presented by Mr. Monte Ross, and the development of a two part manual. The lectures, which are to deal with laser receivers and systems, will include the subject matter of Task I. The manual will include the collating of all material presented in the lectures and will consist of two parts:

Part 1.
1. Radiation Laws and Statistics
2. Noise and Fluctuations
3. Detection Statistics
4. Information Theory Aspects

Part II.
1. Receiving Devices
2. Receiving Techniques
3. Receiving Systems
4. Electro-Optic Devices

Five lectures were given in the second quarter and included the material of Part I above.

1.2 Discussion

No lectures were given in the fourth quarter. The first draft of Part I of the manual has been essentially completed, and work on Part II of the manual has been started.

1.3 New Technology

There are no reportable items under Task II within the meaning of the New Technology clause of NASA Form 1162 dated September 1964.

1.4 Program for Next Reporting Period

Part I of the manual will be essentially completed in the next quarter. Effort will be expended in developing subject material for Part II.

1.5 Conclusions and Recommendations

Five of the ten lectures have been delivered. Part I of the manuals will essentially be completed in the next period and effort will be directed to Part II of the manuals.

2. TASK III EFFORT

2.1 Introduction

The objectives of Task III, as modified, consists first, of developing and delivering one experimental Dynamic Crossed-Field Electron Multiplying (DCFEM) light demodulator, and second, of developing and delivering two improved experimental DCFEM light demodulators with various characteristics including minimum small signal power gain of 100 DB, operation with a lightweight permanent magnet, and other characteristics as mutually agreed upon.

The DCFEM is a device which incorporates many desirable features of static multipliers, such as low noise, exceptionally high amplification, and good spectral response; it has the additional advantage of providing wide signal bandwidth and a much simpler cathode and secondary emission structure. It has superior characteristics when compared with other available devices capable of detecting high frequency modulation.

This device is the first photomultiplier with microwave response. It enables use in instrumentation and scientific experiments where pulses of a nanosecond or less need to be detected in a sensitive manner.

The DCFEM has linear and stable gain over a wide range of operating conditions and can provide unsaturated outputs exceeding one MA, thereby eliminating the need for post detection amplification.

The high sensitivity and large bandwidth of a microwave-bandwidth photomultiplier results in instrument capabilities not previously possible; its specifications show the feasibility of laser systems for space communications and high-resolution radar.

A schematic diagram of the basic detector configuration is indicated in Figure 1. This figure shows two electrodes incorporated in the high electric field region of a rectangular metal cavity resonant at 3 GC. Typical parameters for this configuration are an inter-electrode spacing of 3 mm, and an electric field intensity in the range of 10^5 to 10^6 volts/meter, providing eight multiplication stages. A microwave pump source of not more than a few watts is needed. The active electrode (secondary emission surface) is Beryllium-Copper, Magnesium Oxide or some other suitable material. A small area (20 mm^2) of the active electrode is covered with a photocathode chosen for the spectral response desired. An external magnet supplies a uniform field of about 500 gauss. The length of the column supporting the pedestal is chosen for the 1/4-wavelength resonance mode. It is to be noted that only three external electrical connections are required in contrast to the ten or more connections commonly required with electrostatic photomultipliers.

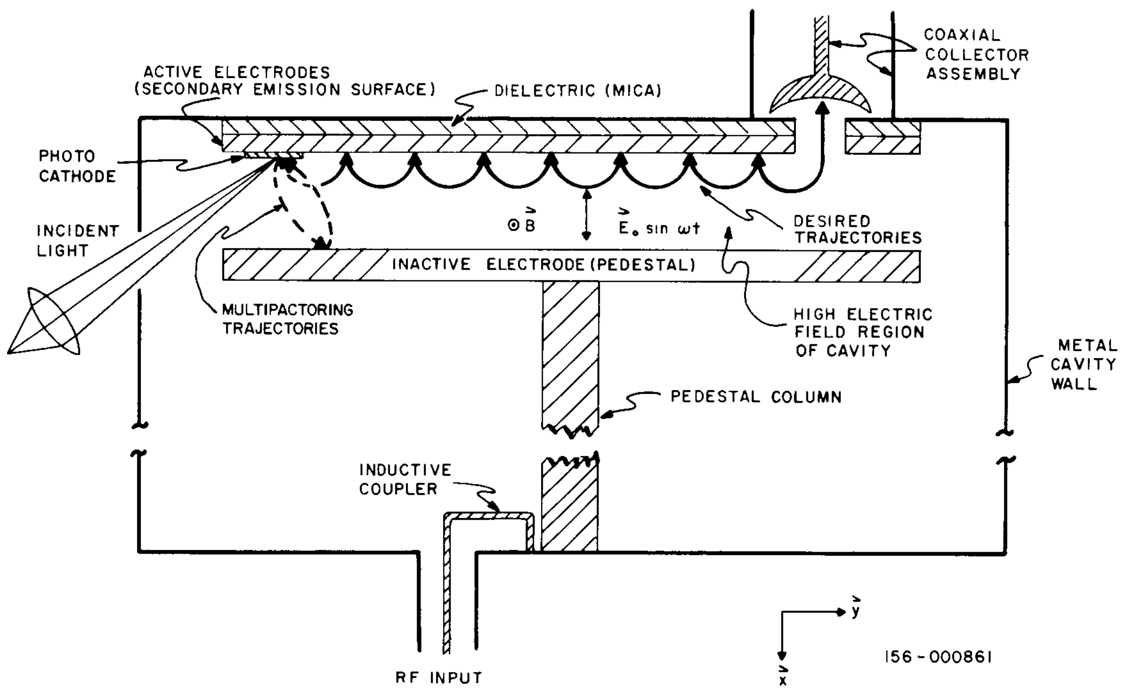

Figure 1. Schematic Diagram of Dynamic Crossed-field Electron Multiplier.

The electron multiplication in the detector is realized by providing a region in which there are two spatially uniform crossed fields. In Figure 1 the static magnetic field points out of the plane of the paper, and the microwave electric field lies vertically in the plane. The region is bounded by two electrodes, one active electrode having a high secondary emission ratio, δ , and the other an inactive electrode or pedestal having a δ of less than unity. Incident light on the photocathode produces photoelectrons which are accelerated initially in the positive-x direction during the positive portion of the microwave voltage cycle. However, the magnetic field curves the paths as shown, and during the negative portion of the cycle the electrons impinge back onto the active electrode where they produce secondary emission electrons. Each of these secondaries is accelerated and curved back onto the active electrode, where additional secondaries are produced. This multiplication process is repeated for n stages, after which the electrons are collected by the coaxial collector assembly.

Work in the first quarter determined that for high vacuum purposes it would be an improvement to re-design the cavity in a cylindrical geometry as shown in Figure 2, rather than in a rectangular geometry. This cylindrical geometry is smaller and easier to fabricate, assemble, and align and its electrical characteristics are as good as or better than the rectangular configuration.

Work in the second quarter centered around construction and testing of the cylindrical geometry DCFEM tube shown in Figure 3. Three tubes were constructed and tested: One leaked severely and was discarded; one had a mechanical malfunction and was disassembled for modification; and one tube was operated to obtain preliminary data. Preliminary data from DCFEM tests indicated frequency response to at least 1 KMC/S. Photo-beats up to 600 MC/S have been detected from a gas laser source.

Work in the third quarter consisted of evaluating factors affecting detector life and in obtaining experimental data for DCFEM operation.

Work in this reporting period, the fourth quarter consisted of evaluation of detector parameters and characteristics and the fabrication and delivery of a new tube with reduced drive power requirements.

2.2 Discussion

2.2.1 Tube Construction and Characteristics

A new detector was vacuum brazed and the body was leak checked. No leaks were discovered. The tube was then completely assembled, as previously described, and the photocathode was formed. The DCFEM detector was found to operate satisfactorily. It was then tested and shipped to NASA, Goddard Space Flight Center.

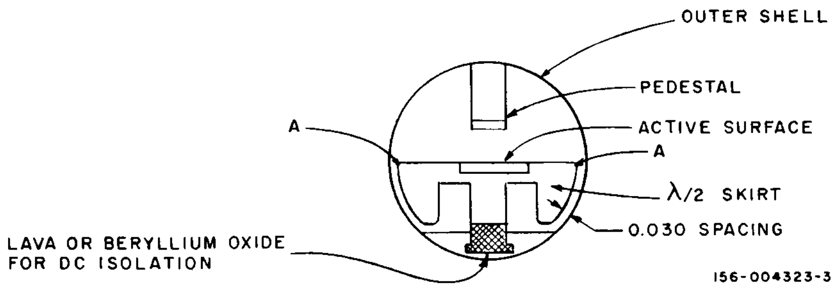

Figure 2. Cylindrical Cavity Using Non-Contacting Microwave Short Circuit.

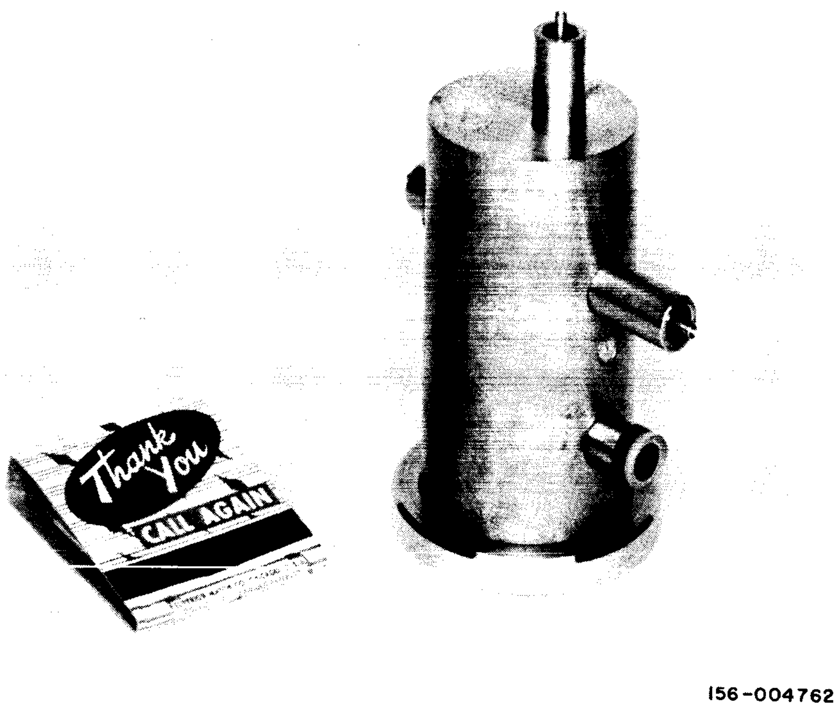

Figure 3. DCFEM (Cylindrical Geometry).

The delivered tube was of the cylindrical configuration, shown in Figures 2 and 3, and had a 2 mm spacing between the pedestal and the secondary emission surface. This reduced spacing resulted in a drive power requirement of only 1.75 watts. The optical input window was Sapphire and the cathode was Antimony-Cesium, yielding an S-4 response for the tube. The small signal current gain of the detector was found to be greater than 10^5 at recommended operating conditions. Additional gain can be realized, however, it may tend to reduce tube life. The delivered DCFEM light demodulator was designed towards the objective of a 3 DB signal to noise ratio when detecting 10^{-12} watts of 6321 AU radiation with a modulation frequency of 3 KMC and a detection bandwidth of 1 KC.

Efforts on tube development and improvement included the reduction in spacing between the pedestal and secondary emission surface, as referenced above. Construction of a second tube with 2 mm spacing was also started. This tube will be used for evaluation prior to further reducing drive power input requirements through a 1 mm pedestal-secondary emission surface spacing.

Replacement of the electromagnet with a lightweight permanent magnet was investigated. Contacts with manufacturers indicate that the type of magnets required are available. However, exact design parameters (field strength, configuration, etc.) must be obtained before procurement.

An investigation of photosurfaces was initiated. Surface types S-17 and S-20 were discussed with representatives of Northwestern University and Warnecke Electrons Tubes, Inc. Information is being evaluated and must be supplemented before any decisions can be reached.

An evaluation was also made of mesh pedestals for DCFEM application. Molybdenum mesh .005 in. thick with 24 lines per inch and 70% optical transmission was evaluated through cold tests. It was found the pedestal was not physically stable with the .005 in. mesh and could not be used. Molybdenum mesh .010 in. thick has been obtained and will be evaluated.

2.2.2 Operating Instructions for DCFEM

The DCFEM, as shipped, is mounted and correctly aligned in a holder/electromagnet assembly. The device is ready for use when connected to the proper power sources. The serial number of the device is 651. The following instructions apply to this tube.

Terminals, Connectors, and Power Sources

Terminals and connectors are shown in Figures 4 and 5. The input drive terminal is a type "N" connector and is located just under the optical input window. The output connector is also type "N" and is located opposite the input window. The remaining connections, for the bias voltage

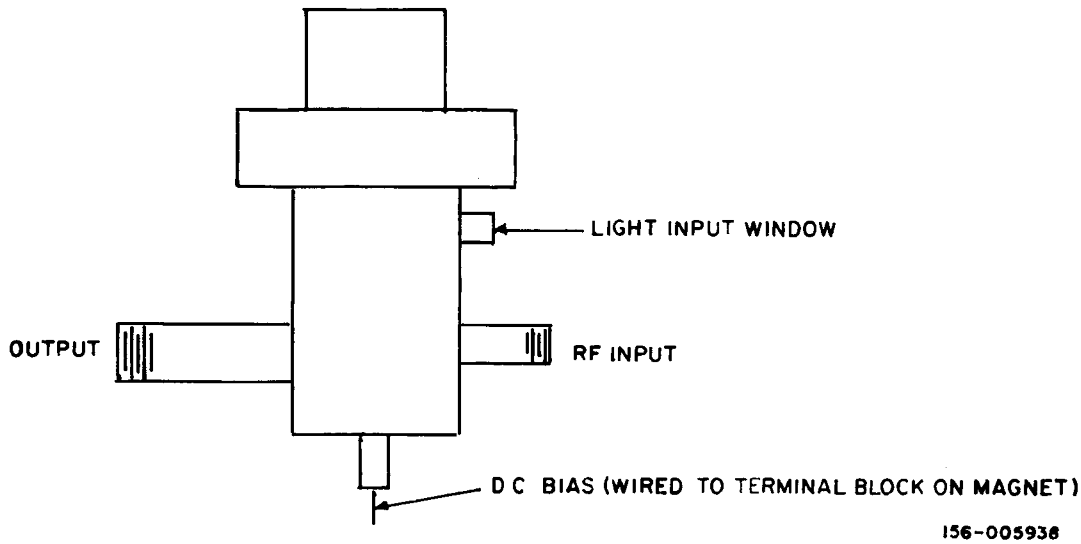

Figure 4. Side View of DCFEM Demounted from Magnet.

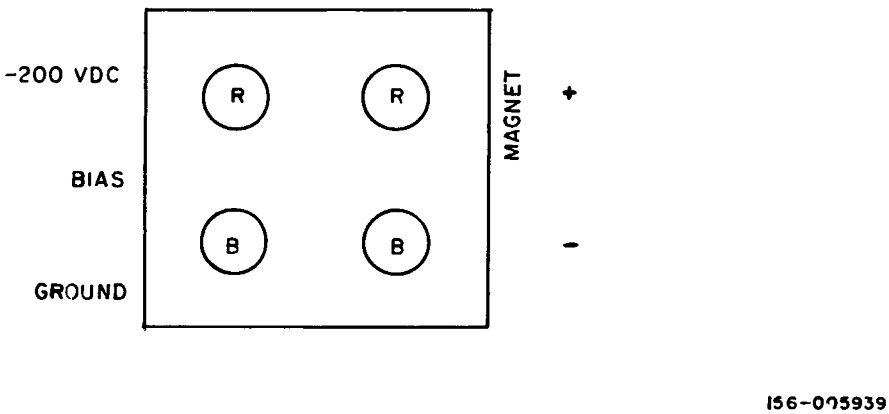

Figure 5. Terminal Block on Side of Magnet.

and the electromagnet, are located on a terminal block on the side of the magnet structure. Table 1 lists the necessary power sources.

Table 1. Power Sources

Function	Connector Description	Power Source
Magnet	Red (+) Black (-) Terminals Marked "Magnet, +-"	Variable to at least 20 VDC at 2 Amps.
Bias	Red (-) Black (Gnd) Terminals Marked "-200 VDC, Bias, Ground"	Variable, nominal rating 200 VDC at 25 milliamps
Microwave Power In	Type N	3.025 GC at 1.75 watts
DCFEM Output	Type N	50-ohm Termination Required

Important Notes

1. A microammeter, with shunts if necessary, should be used in the bias circuit to monitor output photo current.

2. The DCFEM output should be connected to a 50-ohm termination. This could be the input of a well matched receiver or spectrum analyzer.

Turn On Procedure

The following sequence should be followed (see Figure 6):

1. Connect DCFEM output to desired termination.

2. Apply power to magnet. Adjust current to 2 amperes DC.

3. Apply bias voltage. Adjust to -200 VDC. (There will be about 1 microampere of leakage current.)

4. Allow some light to fall on the cathode. (Avoid light intensities which would produce cathode heating.)

5. Apply microwave power. Adjust to 1.75 watts at 3.025 GC. (Caution: Excess RF power may produce instability. Insufficient power will drastically reduce DCFEM gain.)

6. Check indication of photo current on bias ammeter. Adjust RF frequency until there is a photo current. (If there is no photo current, other than leakage, check steps 2 through 5.)

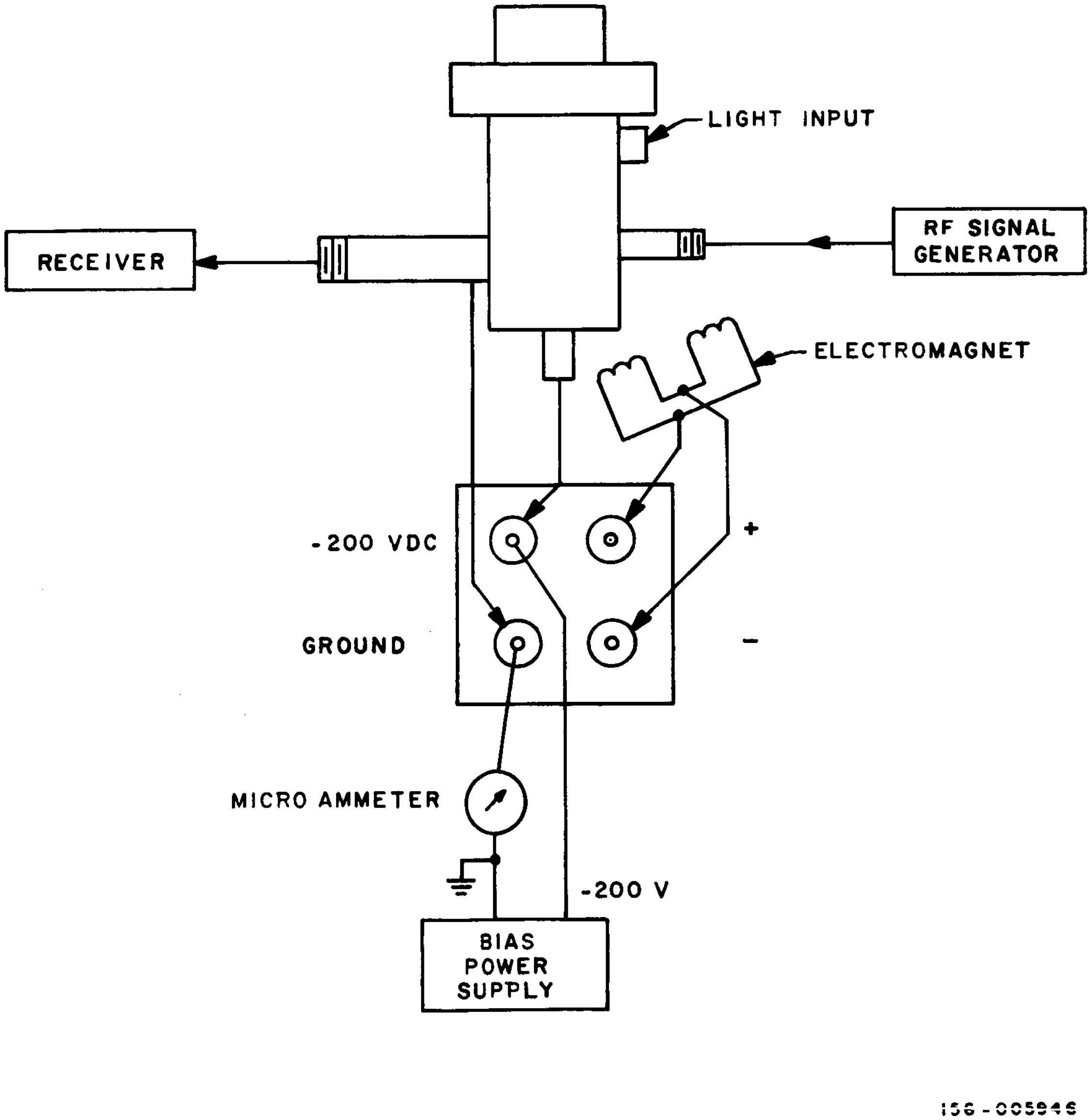

Figure 6. Hook Up Diagram for DCFEM.

7. After an indication of photo current, adjust magnet current, bias voltage, and drive frequency for maximum photo current. (Caution: Do not operate the device with continuous photo current greater than 200 microamperes for extended periods. Low duty cycle pulsed outputs in excess of 10 milliamperes are possible and can be used.)

NOTE

The final values of bias voltage and magnet current should be within 10% of the nominal values given.

Turn Off Procedure

The following sequence should be followed:

1. Turn off RF power input first.

2. Turn off bias voltage.

3. Turn off magnet power.

2.3 New Technology

A review of work performed under the subject contract has been performed in accordance with the provisions of NASA Form 1162 (September 1964), "New Technology." This review indicates that there is one reportable item under Task III. Apart from this one item (reported below) there is no "New Technology" within the meaning of the term as defined in NASA Form 1162 (9 - 64).

2.3.1 Reportable Item (Number One of One)

Item/Nature of Item

An improvement in the Dynamic Crossed-Field Electron Multiplying light demodulator (hereafter called the DCFEM) first actually reduced to practice and consisting of successful operation of a re-designed cylindrical cavity configuration.

Purpose

To provide a DCFEM that is smaller and easier to fabricate, assemble, and align, to improve the high vacuum envelope, and to provide electrical characteristics as good or better than a rectangular configuration DCFEM.

Operation/Physical Characteristics

The Dynamic Crossed Field Electron Multiplier (DCFEM) can be described as a fast response photomultiplier which has the capability of detecting microwave modulated light. It transcends the normal response time limitations inherent in static field devices by utilizing a time varying crossed electric and a static magnetic field to eliminate the transit time spread which occurs among electrons as they proceed along the amplifying (secondary emission) stages of the tube.

Operation of the DCFEM is indicated in Figure 7 and described below.

Figure 7 shows two electrodes incorporated in the high electric field region of a rectangular metal cavity resonant at 3 GC. Typical parameters are an inter-electrode spacing of 3 mm, and an electric field intensity in the range of 10^5 to 10^6 volts/meter, providing eight multiplication stages. A microwave pump source of not more than a few watts is needed. The active electrode (secondary emission surface) is Beryllium-Copper, Magnesium Oxide or some other suitable material. A small area (20 mm^2) of the active electrode is covered with a photocathode chosen for the spectral response desired. An external magnet supplies a uniform field of about 500 gauss. The length of the column supporting the pedestal is chosen for the 1/4-wavelength resonance mode. It is to be noted that only three external electrical connections are required in contrast to the ten or more connections commonly required with electrostatic photomultipliers.

The electron multiplication in the detector is realized by providing a region in which there are two spatially uniform crossed fields. In Figure 7 the static magnetic field points out of the plane of the paper, and the microwave electric field lies vertically in the plane. The region is bounded by two electrodes, one active electrode having a high secondary emission ratio, δ , and the other an inactive electrode or pedestal having a δ of less than unity. Incident light on the photocathode produces photoelectrons which are accelerated initially in the positive-x direction during the positive portion of the microwave voltage cycle. However, the magnetic field curves the paths as shown, and during the negative portion of the cycle the electrons impinge back onto the active electrode where they produce secondary emission electrons. Each of these secondaries is accelerated and curved back onto the active electrode, where additional secondaries are produced. This multiplication process is repeated for n stages, after which the electrons are collected by the coaxial collector assembly.

The purpose of the resonant cavity is to provide the required high electric field with the lowest possible RF power input.

The cavity configuration is of the re-entrant type, capacitively loaded at one end with a rectangular plate (pedestal). The photocathode and secondary emission surface (active surface) is located on the end of the wall opposite the pedestal.

The active surface is isolated (for DC) from the body of the cavity so that small DC potentials can be realized between the active surface and the pedestal. Direct current isolation provides a simple method of directly measuring photo-emission and also allows modification of electron trajectories.

It has been determined that for high vacuum purposes it would be an improvement to re-design the cavity in a cylindrical geometry, as shown in Figure 8, rather than in a rectangular geometry. This cylindrical geometry is smaller and easier to fabricate, assemble, and align and its electrical characteristics are as good as or better than the rectangular configuration.

The RF power is introduced into the cavity by a simple capacitive probe, replacing the inductive loop used in earlier tubes. Probe coupling is easier to fabricate, assemble and align, and still maintains excellent electrical characteristics.

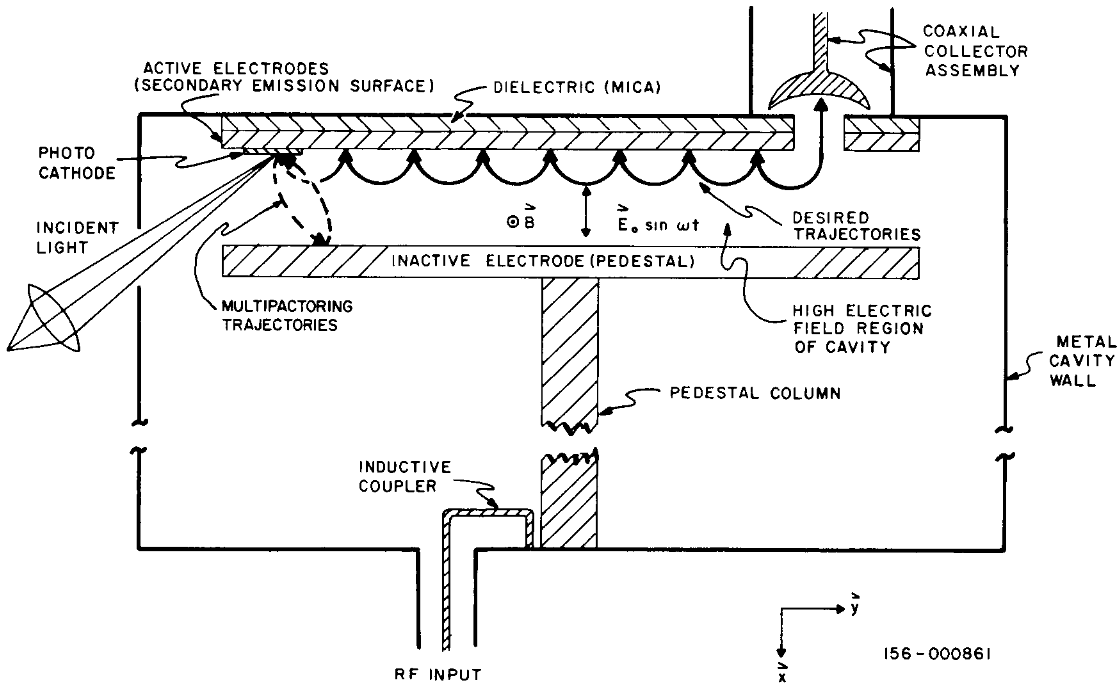

Figure 7. Schematic Diagram of Dynamic Crossed-field Electron Multiplier. (New Technology Section)

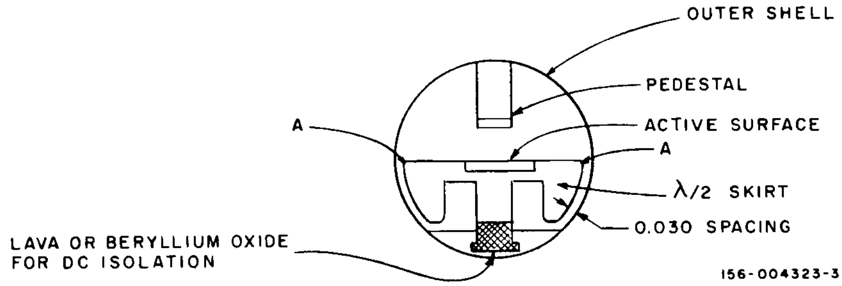

Figure 8. Cylindrical Cavity Using Non-contacting Microwave Short Circuit. (New Technology Section)

2.4 Program for Next Reporting Period

Development and improvement of the DCFEM will continue in the next reporting period through four investigations. First, the number of electron multiplication steps on the active secondary emission surface will be reduced. This will be done to reduce the sensitivity of the tube to variations in input power, also reducing power input stability requirements. Second, the spacing between the pedestal and the secondary emission surface will be decreased to reduce the microwave power input requirement. Third, a .010 in. Molybdenum mesh pedestal will be constructed and evaluated. The mesh should further reduce, or eliminate, instability of the detector and also will allow pedestal coverage of the entire cathode area (since the mesh has seventy-percent optical transmission). Fourth, the collector configuration will be redesigned to reduce mismatch. Such a reduction in mismatch would further reduce any degradation in frequency response.

2.5 Conclusions and Recommendations

A reduction in spacing between the pedestal and secondary emission surface was realized which reduces the microwave drive power to 1.75 watts. A newly constructed DCFEM, with the above reduced power requirement, was shipped to NASA, Goddard Space Flight Center, complete with holder/ electromagnet assembly and detailed operating instructions.

An evaluation of .005 mesh pedestals was completed with negative results, thicker mesh being indicated. A photosurface investigation was initiated on types S-17 and S-20, and replacement of the electromagnet with a permanent magnet was started through discussions of design parameters with manufacturers. Construction was also started on a new DCFEM.